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THE EXPERIMENTAL STUDIES ON THE CHEST WALL REPLACEMENT WITH POLYVINYL FORMAL SPONGE

by

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CHAPTER 1. INTRODUCTION

For a radical operation on a malignant tumor originating in the chest wall, resection of a wide area of the chest wall including the tumor is required, and sometimes the resection of the entire area of the chest wall, even including the pleura, is necessary. And as far carcinoma of the lung, in the metastasis on the parietal pleura, this naturally necessitates the resection of the chest wall concurrent with lobectomy, if a cure is to be effected.

Thus, the problem arises as a result of a radical operation on a malignant tumor originating in the chest wall, whether the defects may be properly replaced. As it is imperative for the pleural cavity to be rendered airtight, and moreover, paradoxical respiration be prevented, a perfect replacement of such defects is never a simple and easy problem. Therefore, after this operation such unpleasant symptoms as a distinct reduction of pulmonary function and difficulties of expectoration of tracheobronchial secrations may follow.

URBAN,[24] SUGARBAKER[22] and others[19] emphasized the cleaning up of the internal mammary lymphnode chain, or removal of the anterior chest wall, in a radical operation on the carcinoma of the breast. They reported that satisfactory results would be obtained by the removal of a wide area of the chest wall, provided that a distant metastasis was not yet observed in a recurrence of the carcinoma of the breast. Since then the problem of a wide area of defects on the chest wall, keeping pace with the recent progress attained in the chest surgery, is attracting keen attention in interested quarters.

When a wide area of the chest wall is removed, with reference to respiratory function, not only deformities of the thoracic cage will be brought about but also a complete closure of the chest wall will be rendered necessary. With this in view, many procedures have so far been undertaken. KIRSCHNER (1914) asserted that a replacement of defects in the chest wall is possible with the use of fascia lata. He was successively followed by WATSON and JAMES[26] (1947), who carried out a series of experiments in this line, and reported that there is no resulting danger of hernia of the lung after the operation. CAMPBELL[6] (1950) asserted that an adequate support would be obtained by using fascia lata and latissimus dorsi muscle. On the other hand, VORGER (1898) suggested the use of bone graft and periost. Experiments

according to this view were undertaken by MAURER and BLADES[15] (1946), DAILEY[7] (1950) and others.

These methods depending on the use of autograft, will require operative procedures, and moreover its use will naturally be placed under certain limitations, where the defects are of major proportions.

Recently a method was worked out which calls for certain foreign material to replace defects. For this purpose, EFFLER and BLADES[9] (1946) and BEARDSLEY[2] (1950) used a tantalum plate which is accompanied with little foreign body reaction. Their method proved successful for preventing paradoxical respiration. However, the plate became loose due to postoperative respiratory movement, and an accumulation of exudation was seen around the plate, necessitating its removal sooner or later. MORROW[16] (1950), ADA and HEVENOR[1] (1951), EFFLER[8] (1953) and others maintained that by using a tantalum mesh, surrounding connective tissues will invade it and become incorporated with it, and therefore it is not necessary to remove it without danger of a breakdown and disintegration of the mesh.

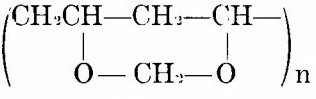
With the remarkable development of plastics in recent years, SOUTHWICK and ECONOMOU[20] (1956) and FITCH and GLASS[11] (1957) reported on the use of polyvinyl formalinized sponge (Ivalon sponge), and HARRISON[13] (1958) reported on the use of Teflon weave. USHER and others[25] (1959), on their part, reported on the use of Marlex mesh.

The author, likewise, aware of the absorbable quality and elasticity of polyvinyl formal sponge[17][18] (Formal sponge) used by Professor NAGAISHI in extraperiosteal plombage for pulmonary tuberculosis, has used it to carry out an experiment on replacement of defects on dogs' chests walls.

CHAPTER 2. EXPERIMENTAL METHODS AND EXPERIMENTAL RESULTS

SECTION 1. MATERIAL FOR REPLACEMENT

The polyvinyl formal sponge (abbreviated as Pvf. sp. here in after), used as the replacing material, was prepared by causing formalin to function on polyvinyl alcohol. It is a tasteless, odorless and white-hued sponge. It is more or less hard when dried up, but when it is soked in water it softens and becomes elastic. Its chemical formula is as described below.



Chemical formula of Pvf. sp.

1) Polyvinyl Formal Sponge Sheet

For the replacing defects on the chest wall, Pvf. sp. was cut into 7 to 8 mm thickness, then soked in running water overnight to obtain a thorough rinsing and for the removal of foreign elements. For 30 minutes prior to operation, it was subjected to boiling disinfection, and was used after being immersed in a penicillin solution.

2) Artificial Rib Made of by Compressing Pvf. Sp.

By taking advantage of "form memory", a feature-property of Pvf. sp., it was compressed at 120°to 130° C by means of the apparatus, shown in Fig. 1, and thus an artificial rib was prepared. The artificial rib showed no changes either in its shape or hardness after being immersed several weeks in 37°C warm water. It was provided with cartilagenous hardness as well as elasticity. It was preserved in a hyamine solution. Before use, it was rinsed with sterilized physiological salt solution.

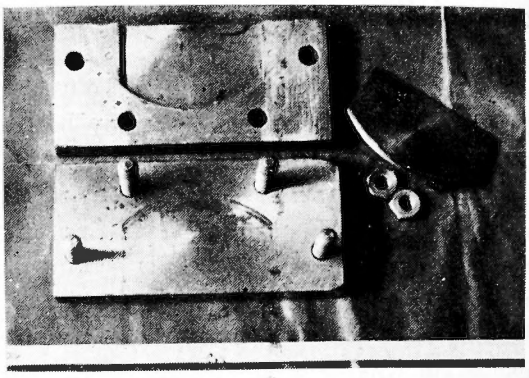


Fig. 1 The apparatus used in making artificial ribs.

SECTION 2. EXPERIMENTAL METHODS

In undertaking the experiment a dog was used. The dog used was an adult mongrel dog (weighting about 10 kg), which was subjected to venous anesthesia with 20 to 25 mg/kg of nembutal, and with a home-made closed-circurationtype anesthetizer, the respiratory tract was maintained and oxygen inhalation was conducted. The primary incision was applied to the right chest wall, the skin flap was reflected, and the area from the 5th intercostal space to 9th intercostal space, including the pectoral muscles, ribs (6 to 9), intercostal muscles and parietal pleura, about 8 cm in length, was removed with en bloc (Fig. 2～6).

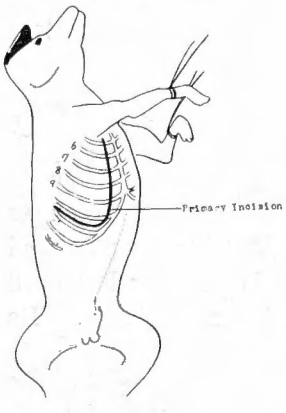


Fig. 2 Position of the dog on the table and the skin incision.

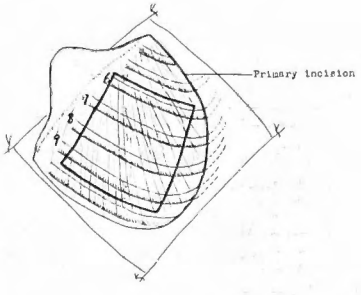


Fig. 3 The skin flap is reflected upward exposing the extrathoracic muscles.

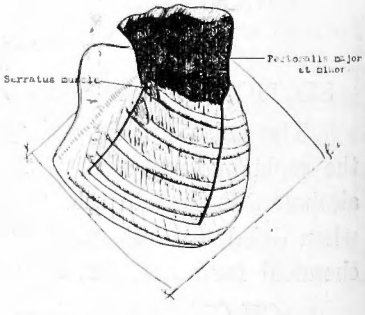


Fig. 4 The pectoralis muscles are removed and the digitations of the serratus magnus divided.

Group A. Instance of Single Replacement with Pvf. Sp. Sheet

Replacement of dog's defects on the aforesaid chest wall was undertaken with Pvf. sp. sheet. For fixing the sponge sheet, interrupted sutures were employed with silk yarn to the adjacent ribs and intercostal muscles. The sutures were carried out with special care to guard against a loosening due to postoperative

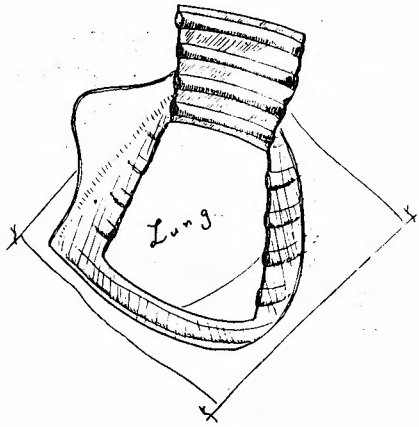


Fig. 5 A block of chest wall 8 by 12 cm is removed. This consists of four ribs and intercostal bundles.

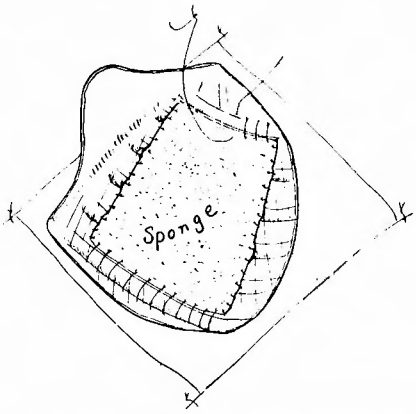


Fig. 6 The Pvf. sp. is fitted into the defects and sutured to the adjacent ribs and intercostal bundles with interrupted sutures.

respiratory movement and to make the chest wall air-tight. Also, between the skin flap and sponge sheet, a number of interrupted sutures were undertaken to prevent the occurrence of dead space.

Group B. Instance of Simultaneous Use of Pvf. Sp. and Artificial Ribs

On the dogs with similar defects in the chest wall, sponge sheet was used as a parietal pleura. As a support to make the chest wall stable, artificial ribs preliminarily prepared, were bridged over sponge sheet. For fixing the rib stumps and the artificial ribs, steel wire was used, while cat-gut was used between the artificial ribs and sponge sheet (Fig. 7 and 8).

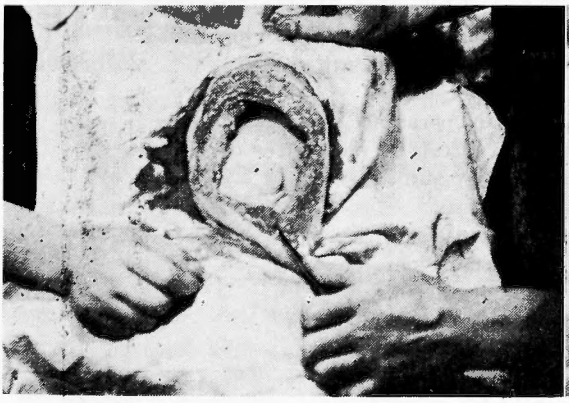


Fig. 7 The defects on the chest wall on dog.

Fig. 8 The defects are replaced with Pvf. sp. sheet and artificial ribs.

In both groups A and B, 300,000 units of penicillin were injected for one week after operation.

Group C. Instance of Control

As control experiment against group A and B, replacement was carried out with only skin flap on similar defects on the chest wall.

SECTION 3. EXPERIMENTAL RESULTS

In each Group A, B and C, there is no instance of death directly resulting from operation. Considering the special nature of this operation, disinfection was carried out with particular attention. Still, considerable cases of infection occurred, the unsuccessful cases including those of general weakness, empyema, persistent fistula, which led to death 3 to 50 days after operation.

The experimental results are as shown in Tables I, II and III. If the cases with complete stopping of drainage after operation are considered successful, 24 cases in Group A included 11 successful cases, with the percentage of success standing at 45.8 %, and 5 cases in Group B included 2 successful cases, with the percentage standing at 40.0 %. Thus, no significant difference was seen between Group A and B (Table II).

Table I. Experimental Result I.

	Experimental Result		
	Dog No.	Sex	Postoperative Course
Group A	No. 1	m.	died from empyema 7 days after operation
	No. 2	m.	cured, sacrificed 6 months after operation
	No. 3	m.	cured, sacrificed 12 months after operation
	No. 4	m.	cured, escaped 35 days after operation
	No. 5	f.	died from general weakness 11 days after operation
	No. 6	m.	died from general weakness 3 days after operation
	No. 7	m.	died from empyema & persistent fistula 50 days after operation.
	No. 8	m.	died from empyema & persistent fistula 3 days after operation.
	No. 9	f.	died from general weakness 9 days after operation
	No. 10	f.	cured, living 19 months after operation
	No. 15	m.	successful, sacrificed 3 months after operation
	No. 18	f.	died from empyema & persistent fistula 24 days after operation.
	No. 19	m.	died from empyema & persistent fistula 25 days after operation.
	No. 23	m.	died from general weakness 6 days after operation
	No. 24	m.	cured, sacrificed 3 months after operation
	No. 26	f.	died from empyema 20 days after operation
	No. 28	f.	died from empyema & persistent fistula 20 days after operation.
	No. 29	f.	died from distemper 27 days after operation
	No. 30	m.	cured, escaped 5 months after operation
	No. 31	m.	cured, sacrificed 1 month after operation
	No. 35	m.	cured, sacrificed 3 months after operation
	No. 36	m.	cured, sacrificed 6 months after operation
	No. 40	m.	died from general weakness 14 days after operation
	No. 41	m.	cured, sacrificed 1 month after operation
G. B	No. 12	f.	died from general weakness 9 days after operation
	No. 16	m.	died from general weakness 6 days after operation
	No. 22	f.	successful, died from anesthesia 30 days after operation
	No. 25	f.	died from empyema 18 days after operation
	No. 33	f.	successful, died from empyema 33 days after operation
G. C	No. 14	m.	died from general weakness 46 days after operation
	No. 17	f.	living 18 months after operation
	No. 37	m.	sacrificed 3 months after operation
	No. 39	m.	sacrificed 3 months after operation

Table Ⅱ. Experimental Result Ⅱ.

	Total Cases	Successful Cases	Successful Ratio
G. A Replaced with Pvf. sp.	24	11	45.8 %
G. B Replaced with Pvf. sp. & Art. Ribs	5	2	40.0 %
G. C Control	4	4	100.0 %

Even in these successful cases, complications such as accumulation of exudation around sponge and empyema, frequently occurred, which eventually led to death.

Thus, when those cases of postoperative complications and eventual death are excluded from the cases tentatively considered successful, 10 cases out of a total of 24 cases in Group A may be considered to be cases of perfect cure, the percentage standing at 41.7 %. 5 cases in Group B included no such cases of perfect cure. Thhs, it is recognized that Group A is obviously superior to Group B (Table III).

Table Ⅲ. Experimental Result Ⅲ.

	Total Cases	Successful Cases	Death & Complication		Cure Cases	Cure Ratio
			Death	Complicat.		
G. A Replaced with Pvf. sp.	24	11	0	1	10	41.7%
G. B Replaced with Pvf. sp. & Art. Ribs	5	2	2	0	0	0 %
G. C Control	4	4	1	0	3	75.0%

In one case among the 11 successful cases in Group A, a little accumulation of exudation was observed around sponge sheet as a result of the sacrifice 3 months after operation.

Two cases of death among the successful cases in Group B, comprised one case of death from empyema 33 days after operation, while the other was one of death while being anesthetized for the purpose of postoperative examination 30 days after operation. A autopsy examination revealed a large amount of exudation in the right pleural cavity.

With Group C, all cases were in perfect health, exept one case where eventual death was due to the general weakness 46 days after operation. It was thus revealed that, in many cases, this extent of defects in the chest wall would not cause such reduction of pulmonary function as would lead to death.

In both Groups A and B, exudation was seen to accumulate in the pleural cavity from the first day after operation. The exudation stopped, leading to cure, in 3 days at the shortest, and 28 days at the longest, or in 14 days on an average among 13 successful cases. At the time of puncture and drainage, 100,000 units of crystal penicillin were injected into the pleural cavity.

As a result of smear and culture test of the exudation, all cases were found to be negative, except one case showing many cocci. Accumulation of exudation is considered to be due to the chemical stimulation of sponge itself rather than to infection. Also, even one case where infection of sponge was observed, cure could be brought about with drainage and administration of antibiotics over a long period of time.

CHAPTER 3. OBSERVATION OF RESPIRATORY FUNCTION AFTER REPLACEMENT OF DEFECTS IN CHEST WALL

A comparative examination of Groups A, B and C was undertaken in order to see what good results were obtained for respiratory funtion after replacing defects in the chest wall.

SECTION 1. EXPERIMENTAL METHOD

The experimental animals were subjected to a fast from the eve of the experiment and venous anesthesia with nembutal 20 to 25 mg/kg. 10 to 20 minutes after injection, when respiration was calmed down, the experiment was carried out.

1) Description of Respiration Curve

The dog was fixed horizontally on a special fixing apparatus, and for recording the respiration curve, kymography was undertaken on a smoked paper with the ISHIYAMA-HURUKAWA device[14] along the central part of the replaced defects and the corresponding point on the opposite side and the median line on the abdomen.

2) Measurement of Arterial Blood Gas

For measuring arterial blood gas, a cylinder with dead space filled with heparin was employed under a similar condition of anesthesia, and arterial blood was taken percutaneously from the femoral artery, and measurement was carried out by using VAN SLYKE-NEILL device.

SECTION 2. EXPERIMENTAL RESULTS

I. Changes in Respiration Curve

In Group A. (instances of replacement with Pvf. Sp. sheet), paradoxical respiration was considerably noted on the first postoperative day, but compared with Group C (instances of Control), the extent of such paradoxical respiration was much lesser. This indicates that replacement with sponge sheet distinctly lowers the extent of paradoxical respiration. With the postoperative course, the extent of paradoxical respiration became lower, and after the elapse of 3 months after opera-

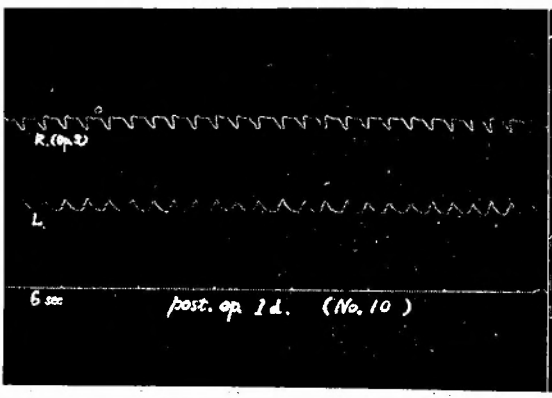


Fig. 9 Respiration curve in the case of replacement with Pvf. sp. sheet, 1st day after operation.
R. (op. s.) : Right (the side of operation)
L. : Left

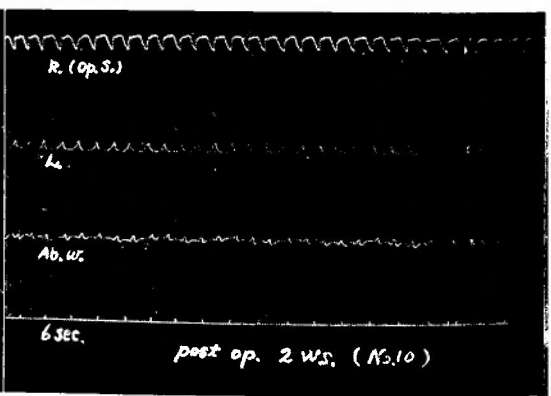


Fig. 10 Respiration curve in the case of replacement with Pvf. sp. sheet, 2 weeks after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

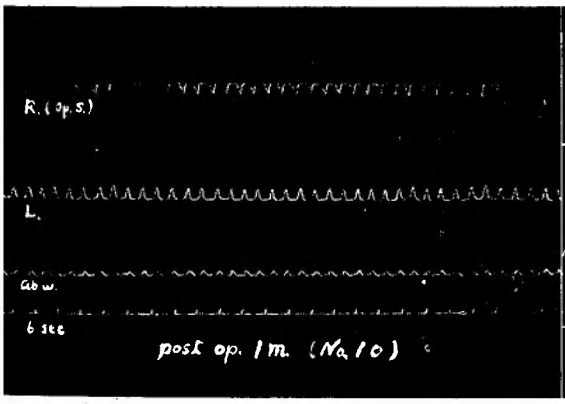


Fig. 11 Respiration curve in the case of replacement with Pvf. sp. sheet, 1 month after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

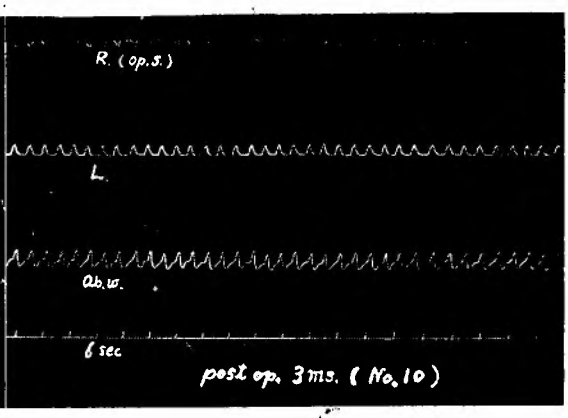


Fig. 12 Respiration curve in the case of replacement with Pvf. sp. sheet, 3 months after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

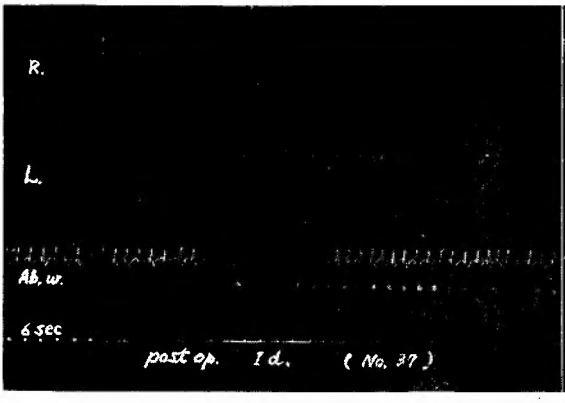


Fig. 13 Respiration curve in the case of control, 1st day after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

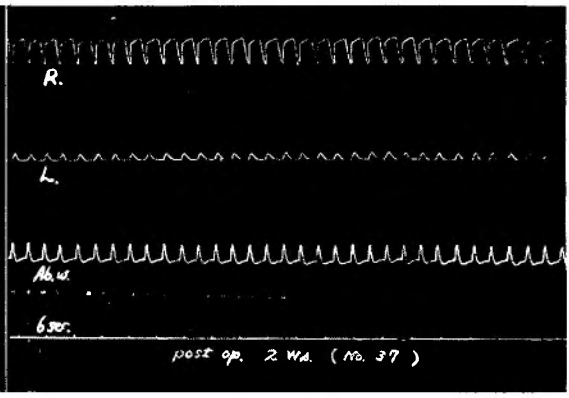


Fig. 14 Respiration curve in the case of control, 2 weeks after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

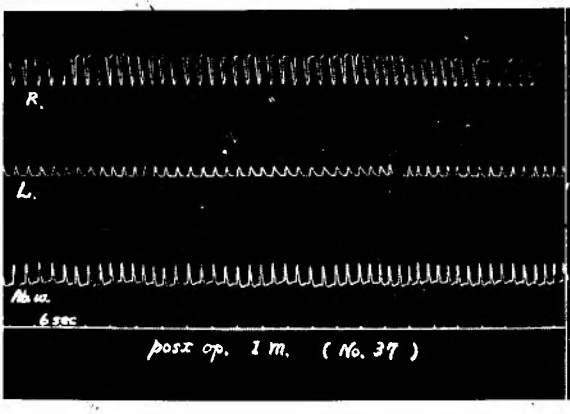


Fig. 15 Respiration curve in the case of control, 1 month after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

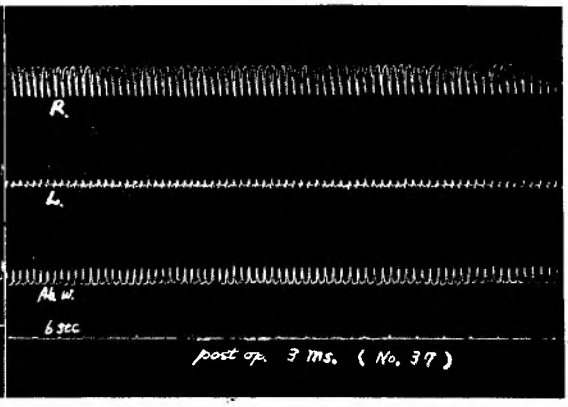


Fig. 16 Respiration curve in the case of control, 3 months after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab. w. : Abdominal wall

tion, its extent was extremely slight (Fig. 9～12).

On the other hand, with Group C (instances of control), paradoxical respiration was distinctly noticed on the first postoperative day, and even 3 months after the operation, recovery was extremely slight (Fig.13～16).

With Group B (instances of use of Pvf. Sp. sheet and artificial ribs), the extent of paradoxical respiration, as compared with Group A, was slighter, due to the use of artificial ribs, 2 weeks after operation (Fig. 17).

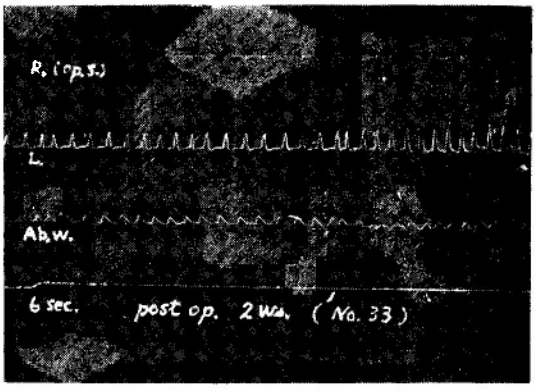


Fig. 17 Respiration curve in the case of replacement with Pvf. sp. sheet and artificial ribs, 2 weeks after operation.
R. (op. s.) : Right (the side of operation)
L. : Left, Ab.w. : Abdominal wall

II Changes in Arterial Blood Gas

The result of the analysis of the arterial blood gas of a healthy dog used in the experiment is as shown in Table IV, which is seen to roughly coincide with what has been reported by many researchers.

Table Ⅳ. The analysis of arterial blood gas (from 15 healthy mongrel dogs)

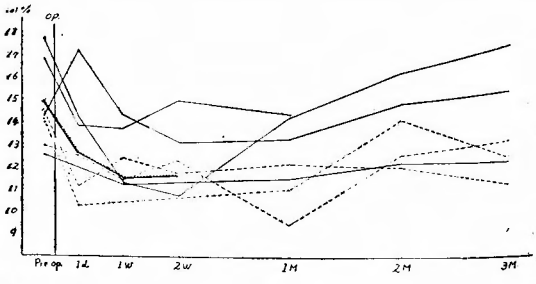
		Max.	Min.	Mean
O_2	Vol%	19.41	13.00	15.9
CO_2	Vol%	49.85	43.87	46.0
O_2 Saturation	%	99.16	88.57	92.8

1) Changes in Amount of Oxygen Contained in Arterial Blood

The changes in the amount of oxygen contained in the arterial blood are as shown in Fig. 18. In all of Groups A, B and C, the amount is seen to decline after operation. In Group A, maximum decline was 3.43 Vol %, with an average standing at 1.08 Vol %; in Group C, maximum stood at 3.85 Vol % and an average at 2.59 Vol%; in Group B, stood at 2.44 Vol%. on the first day after operation.

Up to one week after operation, no increase in the amount of oxygen contained in the arterial blood was observed. After the elapse of one week, however, it gradually tended to increase, and with the passing of time it steadily rose. 3 months after operation, with Group A, the amount was seen to have nearly recovered the preoperative value. But Group C delayed in recovery as compared with Group A.

Fig. 18 Changes in Amount of Oxygen in Arterial Blood



Replaced with Pvf. sp. sheet
Replaced with Pvf. sp. sheet and artificial ribs
Control

2) Changes in Amount of Carbonic Acid Gas Contained in Arterial Blood

The changes in the amount of carbonic acid gas contained in the arterial blood

are as shown in Fig. 19.

In many cases in both Groups A and C, carbonic acid gas increased in amount on the first postoperative day. Some, however, indicated decrease, while in Group B also, decline was registered.

From about one month after operation, changes became fewer. With the passing of 3 months after operation, both Groups A and C were seen to recover their respective preoperative values.

A marked decrease in the amount of carbonic acid gas contained in the arterial blood seen in one case in Group A up to 2 weeks after operation, is caused by a situation of unsatisfactory ventilation due to the accumulation of exudation in the pleural cavity, resulting in hyperventilation.

3) Changes in Oxygen Saturation in Arterial Blood

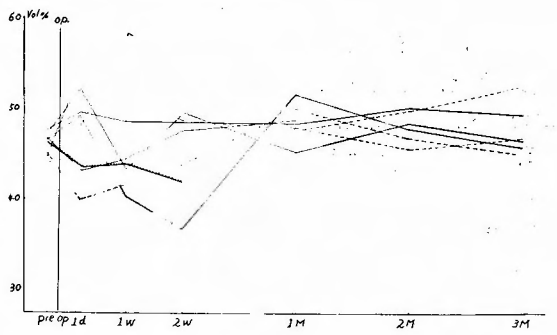
The changes in oxygen saturation in the arterial blood are as shown in Fig. 20.

A decrease of 6.60% on an average was shown on the first postoperative day in Group A. One week after operation, decrease was 6.83% on an average, which was the lowest value seen. As compared with Group C, however, the extent was far slighter. Afterwards, a gradual recovery was seen, and 3 months after operation the preoperative value was nearly recovered. The distinct decrease in the oxygen saturation up to 2 weeks after operation, as seen in one case in Group A, is presumed to have been caused by the accumulation of exudation and the resultant unsatisfactory ventilation.

With Group C, decrease was 11.07% on an average on the first postoperative day, after which a gradual recovery was apparently seen. The extent of recovery, as compared with Group A, was far slighter.

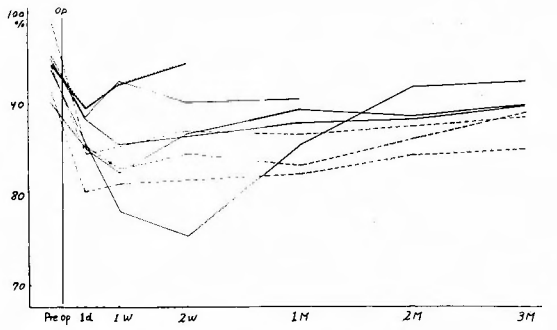
With Group B, decrease was 4.72% on the first postoperative day. As compared with Group A, the extent of decline was slighter, after which the tendency was for increase, and 2 weeks after operation, the preoperative value was nearly recovered.

Fig. 19 Changes in Amount of Carbonic Acid Gas in Arterial Blood



Replaced with Pvf. sp. sheet
Replaced with Pvf. sp. sheet and artificial ribs
Control

Fig. 20 Changes in Oxygen Saturation in Arterial Blood



Replaced with Pvf. sp. sheet
Replaced with Pvf. sp. sheet and artificial ribs
Control

CHAPTER 4. MACROSCOPIC AND HISTOLOGICAL OBSERVATIONS

The dogs with their defects replaced with Pvf. Sp., were sacrificed by bleeding 1, 3, 6 and 12 months after operation, and observed macroscopically. Again, Hematoxylin-Eosin, Van Gieson, Alizarin, Kossa and Pearse stained specimens were prepared which were subjected to histological observation.

I. 1 Month After Operation

A) Macroscopic Findings

No accumulation of exudation was seen in the pleural cavity and around sponge. The replaced sponge was covered with a thin, light grey colored connective tissue capsule, especially on the side of the pleura, being covered with a light grey-colored and lustrous connective tissue capsule. The sponge, at several parts, is seen adherent to the lung and diaphragm. At the joints of rib stumps and intercostal muscles, or in the tissue around the chest wall, no unsatisfactory suture was observed. The sponge, due to the infiltration of the granulation tissue, was apparently slightly hardened. It could be compressed by pressing, and thus, the sponge was observed to maintain its intrinsic nature.

B) Histological Findings

1) Hematoxylin-Eosin Staining

On the side of the pleura) The sponge was covered with a considerably thick granulation tissue. Inward from around the sponge the infiltration of the granulation tissue was comparatively distinct, with considerably large new blood vessels. In the interstices of the sponge, infiltration of considerably many neutrophylic leucocytes, lymphocytes, monocytes and foreign body giant cells could be observed. Excepting slight congestion and atelectasis seen in the lung adherent to the sponge, no marked change was observed (Fig. 21).

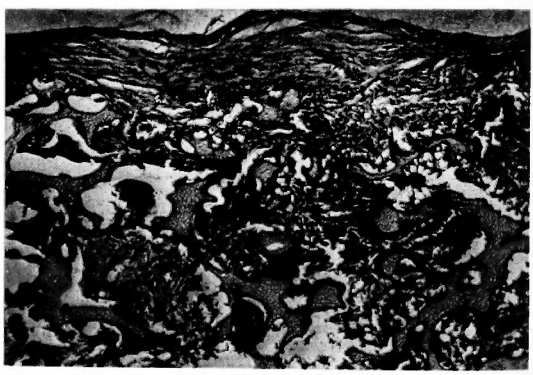


Fig. 21 Section of Pvf. sp. 1 month after operation, pleural side of chest wall, fibrous tissue and round cell infiltrations are observed in the interstices of sponge.
(hematoxylin and eosin ; ×100)

In the central part) In the central part of the sponge, infiltration of granulation tissue was not yet recogneized, but many round cell infiltations were observed.

On the side of the skin) Reaction of the granulation tissue surrounding the sponge on the side of the skin was not so distinct, and the infiltration of granulation tissue into the sponge was also slight as compared with the side of the pleura.

2) Van-Gieson Staining

Inward from around the sponge infiltration of fine connective tissue fibres was observed, the extent of which, however, was slight on the side of the pleura (Fig. 22).

II. 3 Months After Operation

A) Macroscopic Findings

A slight accumulation of exudation was seen between the sponge and the skin in one case, but in two other cases, no such accumulation was seen. The capsule covering the sponge became fibrous and was quite strongly adherent to the sponge surface, while replaced sponge was adherent to the lung and the diaphragm in various degrees. The mediastinum also, was seen to be slightly drawn to the side of the sponge replacement. Also, at the joints with the tissue around the chest wall, no unsatisfactory suture or loosening were noticed (Fig. 23). The replaced sponge apparently satisfactorily tolerates its adjacent tissue, while the sponge itself was harder as compared with what it was one month after operation, indicating on its cut surface a double layer structure, comprising an external layer hardened with the infiltration of the connective tissue and an internal layer still showing sponge condition.

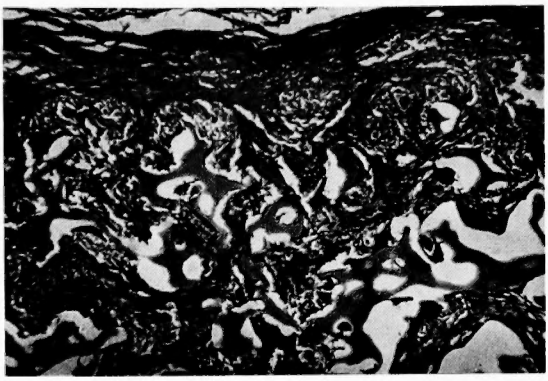


Fig. 22 Section of Pvf. sp. 1 month after operation, pleural side of chest wall, note fine fibrous infiltrations into the interstices of sponge. (Van-Gieson ; ×100)

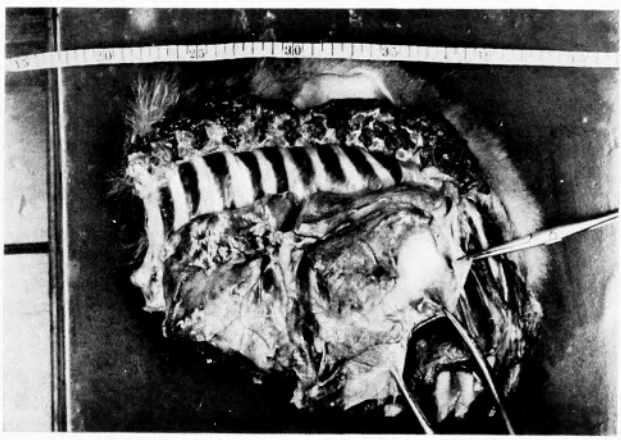


Fig. 23 The excised segment of chest wall containing the replacing Pvf. sp., 3 months after operation, the sponge is adherent to the lung and diaphragm

B) Histological Findings

1) Hematoxylin-Eosin Staining

On the side of the pleura) In certain regions, thickening of the pleura was distinct, fibrosis and atelectasis being sometimes observed in the parenchyma of the lung. The capsule of the sponge became fibrous, and as compared with what was observed one month after operation, the connective tissue fibres became bigger and invaded diffusely, neraly to the central part. Around the sponge its fine fibrous structure was observed, hematoxylin well-stained. Infiltrations of monocytes and foreign body giant cells were distinctly less. Invasions of considerably large new blood vessels were also observed, presenting a comparatively stable histologic picture (Fig. 24).

In the central part) The connective tissue response was slight, only invasion of fine connevtive tissue fibres being observed.

On the side of the skin) While stronger invasion of the connective tissue was seen, which however was slight as compared with the side of the pleura.

2) Van-Gieson Staining

Invasion of the connective tissue fibres was more diffuse as compared with one month after operation, while fibres became bigger (Fig. 25).

3) Alizarin and Kossa Staining

A slight calcic deposition was generally seen in the hematoxylin well-stained regions of the sponge around the sponge, especially on the side of the pleura.

4) Joints between Sponge and Rib Stump

Ingrowth of cartilagenous tissue from the rib stump was seen, which was observed to be invading the intersteices of sponge. Foreign body giant cells were again seen, though few (Fig. 26).

Chondroitin sulphuric acid, staining purple due to Pearse staining, was seen in the cartilagenous tissue, which shows that it is a cartilagenous tissue histochemically (Fig. 27).

Fig. 24 Section of Pvf. sp. 3 months after operation, pleural side of chest wall, diffuse invasion of fibrous tissue into the interstices of sponge and little foreign body reaction are observed. (hematoxylin and eosin ; ×100)

Fig. 25 Section of Pvf. sp. 3 months after operation, pleural side of chest wall. (Van-Gieson ; ×100)

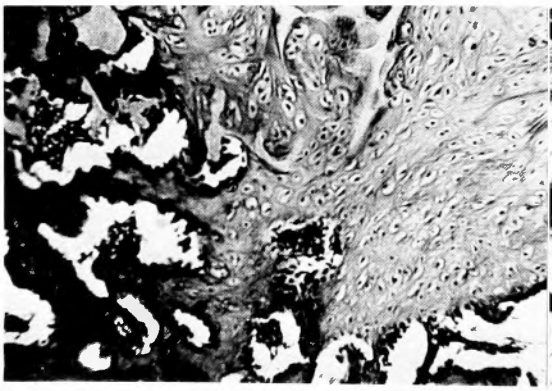


Fig. 26 Section of Junction between Pvf. sp. and rib stump, 3 months after operation, note the ingrowth of cartilagenous tissue into the interstices of sponge. (hematoxylin and eosin ; ×100)

Fig. 27 Section of Junction between Pvf. sp. and rib stump, 3 months after operation, microphotograph shows the chondroitin sulphuric acid histochemically, which is contained in the cartilagenous tissue. (Pearse ; ×100)

III. 6 Months After Operation

A) Macroscopic Findings

In both cases, no accumulation of exudation was observed. Fibrous adhesion was seen between replaced sponge and lung or diaphragm. At this stage, expolication was not easy. Slight attration of the mediastinum to the right side was also seen in both cases. The sponge itself increased its hardness, while the joints with the tissue around the chest wall were perfectly tolerative, especially the sponge adjacent to the rib stump presenting a condition of brownish osseous hardness over 7 to 8 cm (Fig. 28).

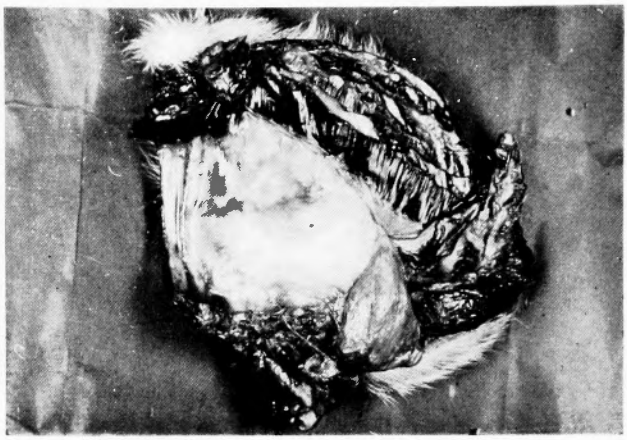


Fig. 28 The excised segment of chest wall containing the replacing Pvf. sp., 6 months after operation.

B) Histological Findings

1) Hematoxylin-Eosin Staining

Invasion of the connective tissue into the sponge, as compared with the case of 3 months after operation, was still more distinct, nearly reaching the central part. The connective tissue fibres were bigger and more diffuse. Around the sponge a vacuolous structure, hematoxylin well-stained, was observed, which was assumed to indicate isolation of fine fibres as the sponge will be assimilated in the organic system, it being melted and absorbed (Fig. 29).

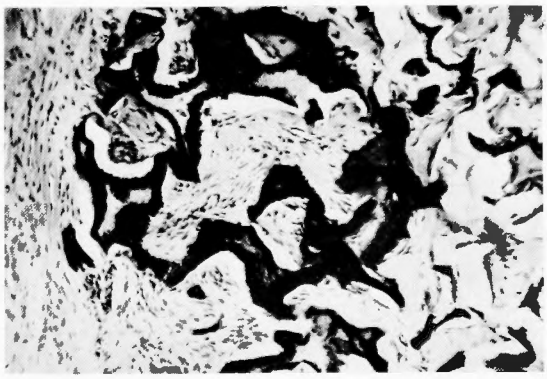


Fig. 29 Section of Pvf. sp. 6 months after operation, pleural side of chest wall, note that fibrous tissues are becoming bigger and more diffuse, and calcic depositions are seen in the sponge. (hematoxylin and eosin ; ×100)

Deep staining by hematoxylin (lack formation), was due to calcic deposition, as shown in Alizarin aud Kossa staining.

2) Van-Gieson Staining

As compared with the 3 month picture, invasion of the

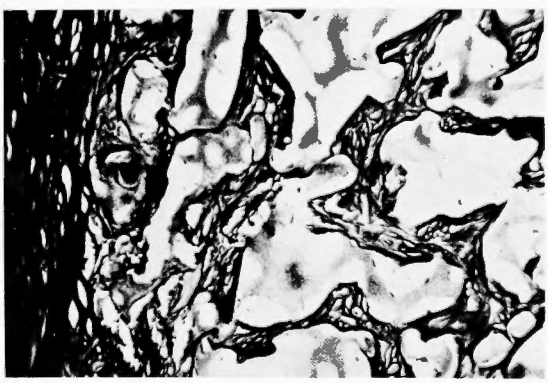


Fig. 30 Section of Pvf. sp. 6 months after operation, pleural side of chest wall.
(Van-Gieson ; ×100)

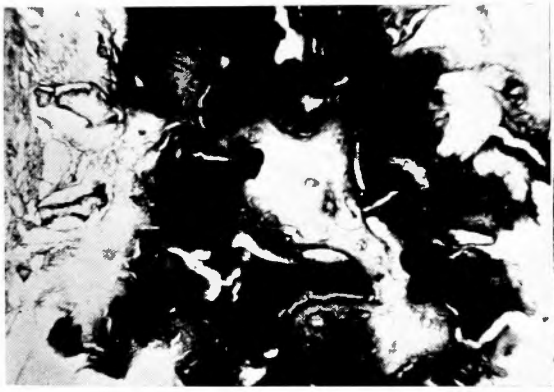


Fig. 31 Section of Pvf. sp. 6 months after operation, pleural side of chest wall, microphotograph shows the calcic deposition. (Alizarin; ×100)

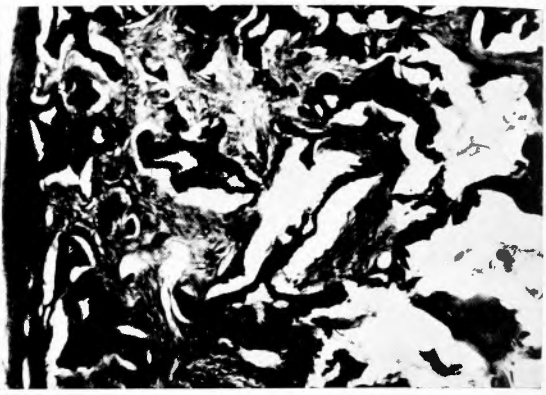


Fig. 32 Section of Pvf. sp. 6 months after operation, pleural side of chest wall, microphotograph shows the calcic deposition. (Kossa; ×100)

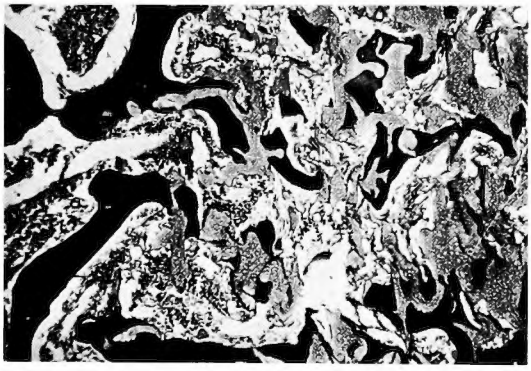


Fig. 33 Section of junction between Pvf. sp. and rib stump, 6 months after operation, note that osseous tissue invades the interstices of sponge, and hematopoiesis is observed among new bone frames. (hematoxylin and eosin; ×100)

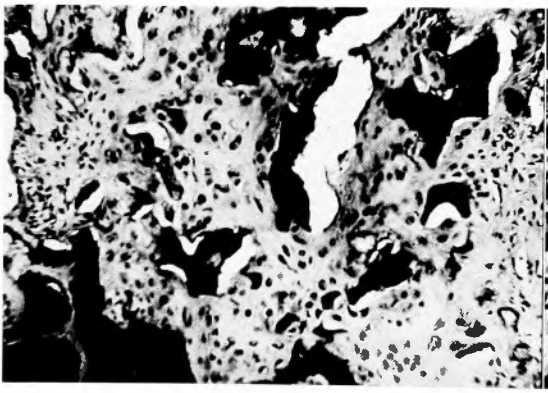


Fig. 34 Section of Pvf. sp. 6 months after operation, microphotograph shows the new growth of cartilagenous tissue in the sponge, not consecutively with the surrounding tissue. (hematoxylin and eosin; ×100)

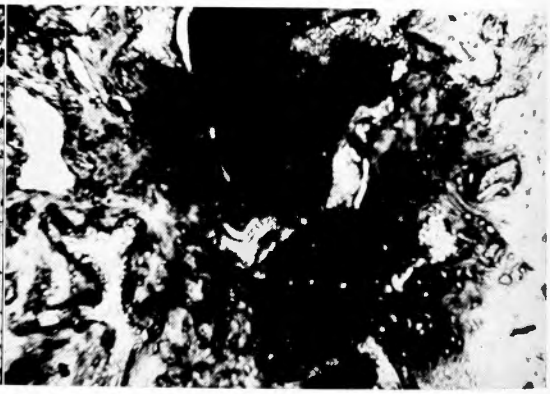


Fig. 35 Section of Pvf. sp. 6 months after operation, microphotograph shows the chondroitin sulphuric acid histochemically contained in the cartillagenous tissue. (Pearse; ×100)

connective tissue fibres became more diffuse, while the fibres became gradually bigger (Fig. 30).

3) Alizarin and Kossa Staining.

Calcic deposition was more distinct as compared with the 3 month picture, especially so on the side of the pleura (Fig. 31, 32). In the central part however, no calcic deposition was observed.

4) Joints Between Sponge and Rib Stump

Invasion of cartilagenous tissue and bone tissue from the rib stump into the sponge was seen, and between the new bone frames hematopoiesis was observed (Fig. 33). Also, the new growth of cartilagenous tissue was seen in island-like shape in the sponge, not consecutively with the surrounding tissue, or, in other words, ectopically (Fig. 34, 35).

IV. 12 Months After Operation

A) Macroscopic Findings

In the thoracic cavity and around the sponge no accumulation of exudation was observed. The replaced sponge was generally adherent to the lung and the diaphragm, while the mediastinum was also slightly attracted to the right side. The cut surface of the sponge still showed a double layer structure, while the external layer increased in thickness and hardness, indicating cartilagenous hardness, as compared with the 6 month picture.

Fig. 36 Section of Pvf. sp. 12 months after operation pleural side of chest wall, the invasion of fibrous tissue into the sponge are becoming more and more diffuse.
(hematoxylin and eosin; ×100)

B) Histological Findings

1) Hematoxylin-Eosin Staining

No marked change was observed in the parenchyma of the luug. From the side of the pleura, strikingly big connective tissue fibres were seen to invade diffusely, while the absorption of the sponge and the calcic deposition were still more distinct as compared with the 6 month picture. Absolutely no foreign body reaction was noted (Fig. 36).

Fig. 37 Section of Pvf. sp. 12 months after operation, pleural side of chest wall, the fibers are becoming more diffuse and bigger.
(Van-Gieson; ×100)

2) Van-Gieson Staining

The connective tissue was seen to invade nearly up to the central part of the sponge, with big connective tissue fibres seen to invade diffusely (Fig. 37).

3) Alizarin and Kossa Staining

Calcic deposition was still more distinct as compared with the 6 month picture, its extent being stronger around the sponge. In the central part of the sponge calcic deposition was not observed.

V. Tentative Summary of this Chapter

A) Macroscopic Findings

In 7 out of 8 cases, accumulation of exudation was not noted in the pleural cavity and around the sponge. The replaced sponge was covered with the connective tissue capsule. Especially the pleural surface was covered with a light grey colored and lustrous connective tissue capsule. Between the sponge and lung or diaphragm, adhesion of various degrees was noted, while the mediastinum also was attracted to the side of sponge replacement. After operation, the replaced sponge was gradually hardened, and 6 months after operation, indicating a double layer structure, consiting of the external layer hardened by invasion of the connective tissue and calcic deposition and the internal layer still showing sponge condition.

With the passing of 6 and 12 months, the external layer became thicker and harder, indicating cartilagenous hardness. Even in the region of joint with the tissue surrounding the chest wall, neither unsatisfactory suture nor loosening was noted; toleration was perfect. 6 months after operation, the sponge adjacent to the rib stump showed brownish, osseous hardness over about 7 to 8 mm, suggesting the growth of a new bone.

B) Histological Findings

Connective tissue reaction was generally observed more distinctly on the pleural side.

Already one month after operation, the sponge was found to be covered with a considerably thick granulation tissue, with invasion of granulation tissue into the sponge, being observed distinctly. Although no such invasion was noted in the central part. Foreign body reaction also was distinct.

3 months after operation, the capsule became fibrous. The connective tissue fibres were also comparatively big and diffuse. Foreign body reaction likewise became extremely slight and invasion of comparatively large new blood vessels was observed, showing a stable histological picture.

With the elapse of 6 and 12 months, the connective tissue fibres became bigger, and had invaded diffusedly, nearly up to the central part. Practically no foreign body reaction was noted.

3 months after operation, calcic deposition was noticed around the sponge, especially on the pleural side, which became more and more distinct with the passing of 6 and 12 months.

At the joints of the rib stump and sponge, 3 months after operation, invasion of cartilagenous and bone tissue into sponge was noticed. 6 months after operation, hematopoiesis was observed between the new bone frames in the sponge.

CHAPTER 5. DISCUSSION

1) What is proper as material for replacing defects in the chest wall?

Basically it is most desirable that, in plastic reconstruction, autotissue be used for replacing.

But, as the defects become larger, the method will unavoidably be placed under certain restrictions, and therefore replacement with such material with little foreign body reaction must be considered.

Especially on the chest wall, it is necessary that a sufficient support be available for preventing postoperative paradoxical respiration. The substance also should be such that it tolerates the adjacent tissues, without necessity of its subsequent removal.

EFFLER and BLADES[9] (1946) and BEARDSLEY[2] (1950) used the tantalum plate. Whenever it was used, however, accumulation of exudation was observed around it, or else it was accompanied with a persistent fistula, making it necessary to have it removed sooner or later.

TAZAWA[23] (1956), likewise, in an experiment with the use of an artificial chest wall consisting of synthetic resin ribs and nylon film, succeeded in preventing paradoxical respiration. But, as he noticed accumulation of exudation around it, he reported on the necessity of removing the artificial ribs one month after operation.

SOUTHWICK and ECONOMOU[20] (1956) maintained that, by the use of Ivalon sponge, it would be possible to obtain a functionnally stable chest wall, while FITCH and others[10][11] (1957, 1958) reported that, by using the compressed Ivalon sponge sheet, no postoperative paradoxical respiration was noted.

According to the experimental results obtained by the author, postoperative paradoxical respiration could be prevented in cases where an artificial chest wall consisting of Pvf. sp. sheet and artificial ribs. However the artificial ribs apparently failed to tolerate the surrounding tissue, and, as compared with the cases where only Pvf. sp. sheet was used, there was a tendency for the exudation to accumulate in the pleural cavity and around the sponge. The percentage of cure also was far lower.

As pointed out by EFFLER[8] (1953), the use of a hard foreign material in some region, such as the chest wall which constantly moves due to respiratory movement, in order to prevent paradoxical respiration, may cause a loosening between it and the neighbouring tissue. Moreover this will bring out an accumulation of exudation as a result of an inflammation due to mechanical stimulation.

In cases where a Pvf. sp. sheet is used, paradoxical respiration is not perfectly prevented in the early stages after operation, but a functionally stable chest wall can be obtained. Moreover, it can tolerate the neighbouring tissue, with the advantage that no subsequent removal is required

2) Effect of Pvf. Sp. Replacement.

On the first postoperative day, in the case of Pvf. sp. sheet replacement, a considerabl degree of paradoxical respiration is observed. Its degree is far lower, as compared with the case of control with the skin flap only as replacement, and thus its effect is obvious. Afterwards, with the passing of time, the sponge becomes hardened, as the connective tissue invades the sponge, and, in keeping with this, paradoxical respiration decreases. 3 months after operation, as the hardness of

the sponge is maintained by calcic deposition, paradoxical respiration becomes extremely slight.

In the case of sponge sheet replacement, the reduction of oxygen saturation in the arterial blood on the first postoperative day is far slighter as compared with the case of control replaced with the skin flap only.

As pointed out also by TAZAWA, this is considered to be caused by the fact that paradoxical respiration is maintained slighter or prevented rather than by the fact that, with the replacement with sponge, the collaps of the lung is prevented to a certain extent and, thus, the reduction of the respiratory area is lessened. Then, with the passing of time after operation, paradoxical respiration is improved, and, together with this, the oxygen saturation of the arterial blood rises up, and 3 months after operation the preoperative value was almost recovered.

3) Fate of Replaced Polyvinyl Formal Sponge

Already one month after operation, a considerable invasion of the granulation tissue into the sponge is observed, while the foreign body reaction remains distinct. 3 months after operation, big and diffuse connective tissue fibers invade the sponge, while the foreign body reaction becomes extremely slight. 12 months after operation, the connective tissue also is seen to invade as deep as the central part. According to Professor NAGAISHI,[17] with the passing of more than one year after operation, absorption rarely occurs, resulting in a more or less stable condition.

3 months after operation, calcic deposition comes to be noted from around the replaced sponge. This seems to be attributable to the effect of cells which emigrate as the sponge is organized, under the effect of which the sponge begin to be dispersed to the fine fibers, and calcic deposition is caused to the melting region of the sponge which is about to be well stained by hematoxylin.

With the passing of 6 to 12 months after operation, furthermore, calcic deposition becomes more manifest, and, together with the invasion of the connective tissue, the replaced sponge itself comes to gain its own hardness.

In an experinent in which Ivalon sponge was inserted into the periosteal bed after the resection of rib in dog, STRUTHERS[21] (1955) observed invasion of the bone tissue into the sponge from the adjacent area. In the experiment undertaken by the author, also invasion of the cartilagenous tissue into the sponge from the rib stump was observed 3 months after operation. 6 months after operation, hematopoiesis could be noted among the new bone frames, which invade the sponge, and it is indicated that the rib stump and the sponge were sufficiently tolerating functionally to each other.

BRODKIN and PEER[4] (1954) maintained that, with the use of tantalum mesh gauze with diced cartilage graft on the chest wall, certain diced cartilage will continue to live without being absorbed, from which the growth of new bone is noticed, resulting in a stable chest wall. On the other hand, FITCH and GLASS[11] (1957), also, proposed the periost to be placed on compressed Ivalon sponge sheet in replacing defects in the chest wall, while an analogical fact was observed in an experiment carried out by the author. The fact refers to the growth of a cartilagenous tissue

in the replaced sponge, not connected with either the adjacent bone tissue or cartilagenous tissue. This is considered to indicate that the bone tissue, cartilagenous tissue or periosteal pieces inserted into the sponge, in some form or other, grew up without being absorbed. Or it may be a metaplasia from the connective tissue already invading the sponge. Nothing certain is known, however.

On the other hand, in the experiment conducted by STRUTHERS, in which Ivalon sponge containing chips of autogenous bone was buried in the rectus abdominis muscle, the chips of autogenous bone was absorbed and remained as calcic deposition 4 weeks after operation. It seems, however, to contradict the above described facts. It seems apparent that the growth of the bone tissue or cartilagenous tissue are related to the site of their introduction. Anyway, this point attracts deep attention.

4) On Carcinogenic Effect of Polyvinyl Formal Sponge

The question naturally arises whether replacement with plastics in a living body might cause a tumor. OPPENHEIMER and others reported on the occurrence of sarcoma in experiments in which various kinds of plastics were implanted in rats and mice subcutaneously. They, however, did not experiment on Pvf. sp. and similar substances.

BROWN and others[5] (1954) in an experiment in which polyvinyl formalinized sponge was implanted subcutaneously in 50 mice, reported the occurrence of fibroma in one case. This tumor, evidently, was caused at a point adjacent to, but distinctly separated from the sponge. However malignant tumor has apparently not been induced in a human patient by the use of plastics.

Lastly, the Pvf. sp., as with all foreign materials, is poorly able to tolerate the presence of infection, and it is considered to be a contraindication to use it on a contaminated field, and therefore special attention should be paid to aceptic technique in using it. Even in one case where infection of sponge was clearly observed, cure could be brought about by means of drainage and administration of antibiotics over a long period of time.

CHAPTER 6. CONCLUSION

The author conducted the experiments on the replacement of defects in the chest wall of dogs, and has arrived at the following conclusion:

1) When a foreign material is introduced as a replacement into a field which constantly moves due to respiratory movement like the chest wall, it is obviously advantageous to use a foreign material with little stimulation. It is of particular importance, however, that it sufficiently tolerates its neighbouring tissue, and thus it is considered improper to use a rigid substance in replacing the defects in the chest wall because it will not tolerate its adjacent tissue and will result in the accumulation of exudation.

2) Polyvinyl formal sponge, as a replacement, will tolerate the surrounding tissues. Already 3 months after operation, the invasion of connective tissue into the sponge is distinctly observed, being accompanied with little foreigin body

reaction and indicating stable histological pictures.

3) 3 months after operation, calcic deposition is observed in the sponge, as well as invasion of a bone tissue or cartilagenous tissue into the sponge. And thus the hardness has been maintained in the sponge itself.

4) With replacement of polyvinyl formal sponge, postoperative paradoxical respiration has been drastically reduced. The analysis of the arterial blood gas proved that good results, also, were obtained.

5) In the light of the results above described, it is considered that in the surgical treatment of the chest wall tumor and carcinoma of the lung, the range of its indication of the resection will be greatly extended by the use of polyvinyl formal sponge.

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和 文 抄 録

Polyvinyl Formal Sponge による胸壁欠損補填の実験的研究

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胸壁の広汎切除を要する機会は屢々あるが，かゝる手術の後には胸郭変形を来たすのみならず，胸壁動揺によつて著明な呼吸機能の低下を来たすことが少くない．

この対策として，われわれは試獣として犬を用い，右胸壁において第5肋間から第9肋間に亘る範囲を，胸筋，肋骨，肋膜をも含んで約8cm長に en bloc 切除を行い，厚さ7～8mmの可吸収性 Polyvinyl Formal Sponge Sheet を以て欠損部を補填したA群，更に Polyvinyl Formal Sponge から作成した代用肋骨を用いて補強したB群，及び対照として皮膚弁のみで補填したC群に対して，手術成功率，術後の呼吸曲線，動脈血ガスの変動について比較検討し，又補填 Sponge の運命を術後1年に亘つて追求，観察した結果次の結論をえた．

Ⅰ．A群24例中，成功例10例で成功率41.7％であり，一方B群5例中，成功例なく，何れも胸腔内滲出液貯溜，膿胸等の合併症を来たし不成功に終つている．

従つて，胸壁のように呼吸運動によつて絶えず動いている処に異物を補填する場合には，それが周囲組織によくなじむことが特に重要であり，代用肋骨のような固いものを用いることは周囲組織となじまずにゆるみを生じ，又毎常その周囲に滲出液の貯溜を来たすので早晩除去する必要があり不適当と考えられる．

Ⅱ．Polyvinyl Formal Sponge の補填によつても，なお術後に或程度の奇異呼吸が認められるが，対照例に比較して遙かに軽度であり，術後経過と共に次第に軽減し，術後3ヵ月目になると極めて軽度となる．又動脈血ガス分析の結果においても対照例に比較してよい結果を示し，術後3ヵ月目には殆んど術前値に近く恢復している．

Ⅲ．補填された Sponge は周囲組織とよくなじみ，術後1ヵ月目ですでに Sponge 中に結合織の侵入がかなり著明に認められ，術後3ヵ月以後になると，異物反応も極めて軽度となり安定した組織像を示すようになる

Ⅳ．術後3ヵ月目になると Sponge に石灰が沈着して来，又肋骨断端から Sponge 中へ軟骨組織或は骨組織が侵入して来て，結合織の侵入と相まつて Sponge 自身に一定の硬度が保有されるようになる．